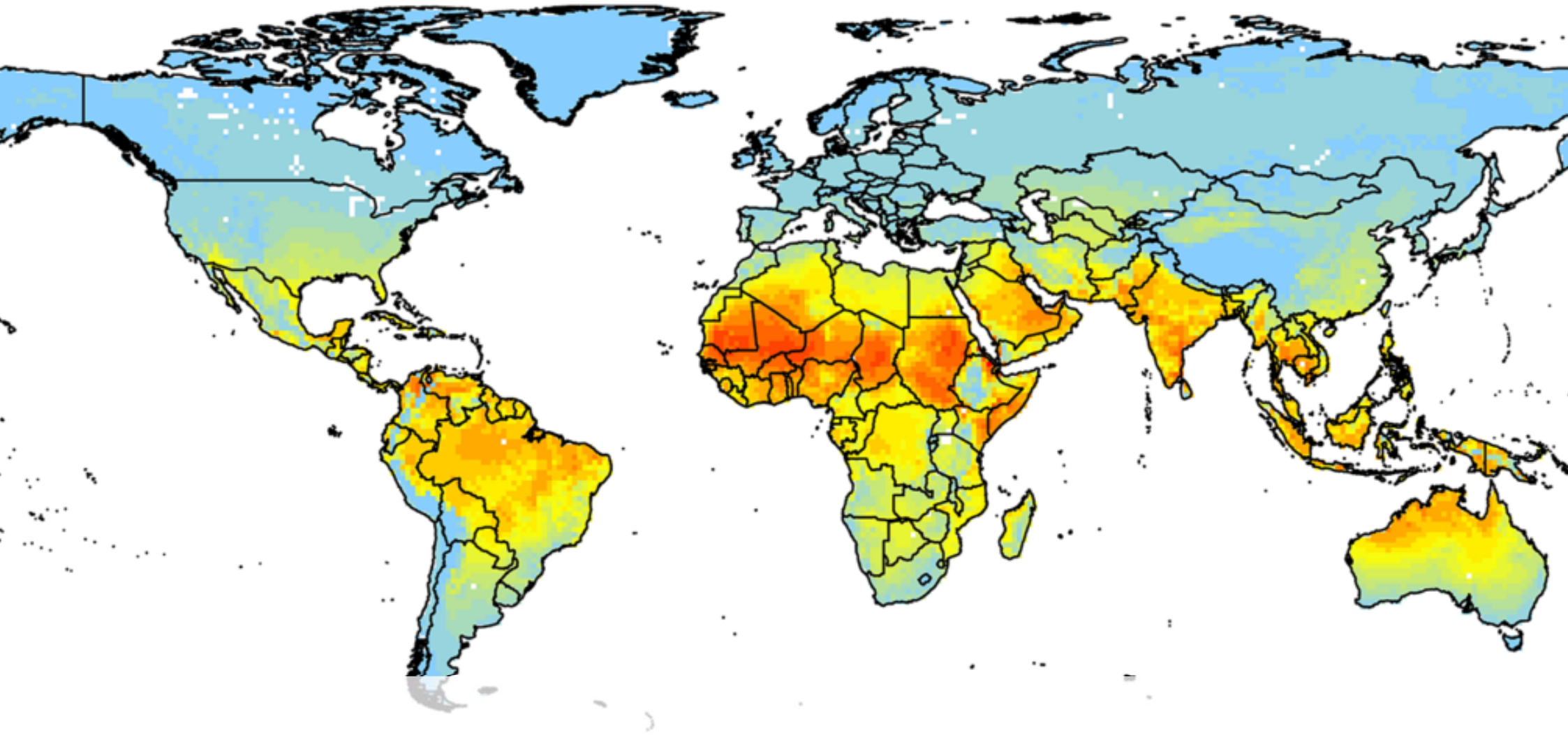
SinBerBEST
Building Efficiency and Sustainability in the Tropics

First move the air, then cool it

Stefano Schiavon

Associate Professor of Architecture
Associate Director of CEDR | Center for the Built Environment
UC Berkeley



People living in the Tropics: ~40% (2019) to 60% (2060)

0 1000 2000 3000 4000 5

Cooling degree days – Rodell et al - www.energy-a.eu

How satisfied are you with the temperature of your workspace?

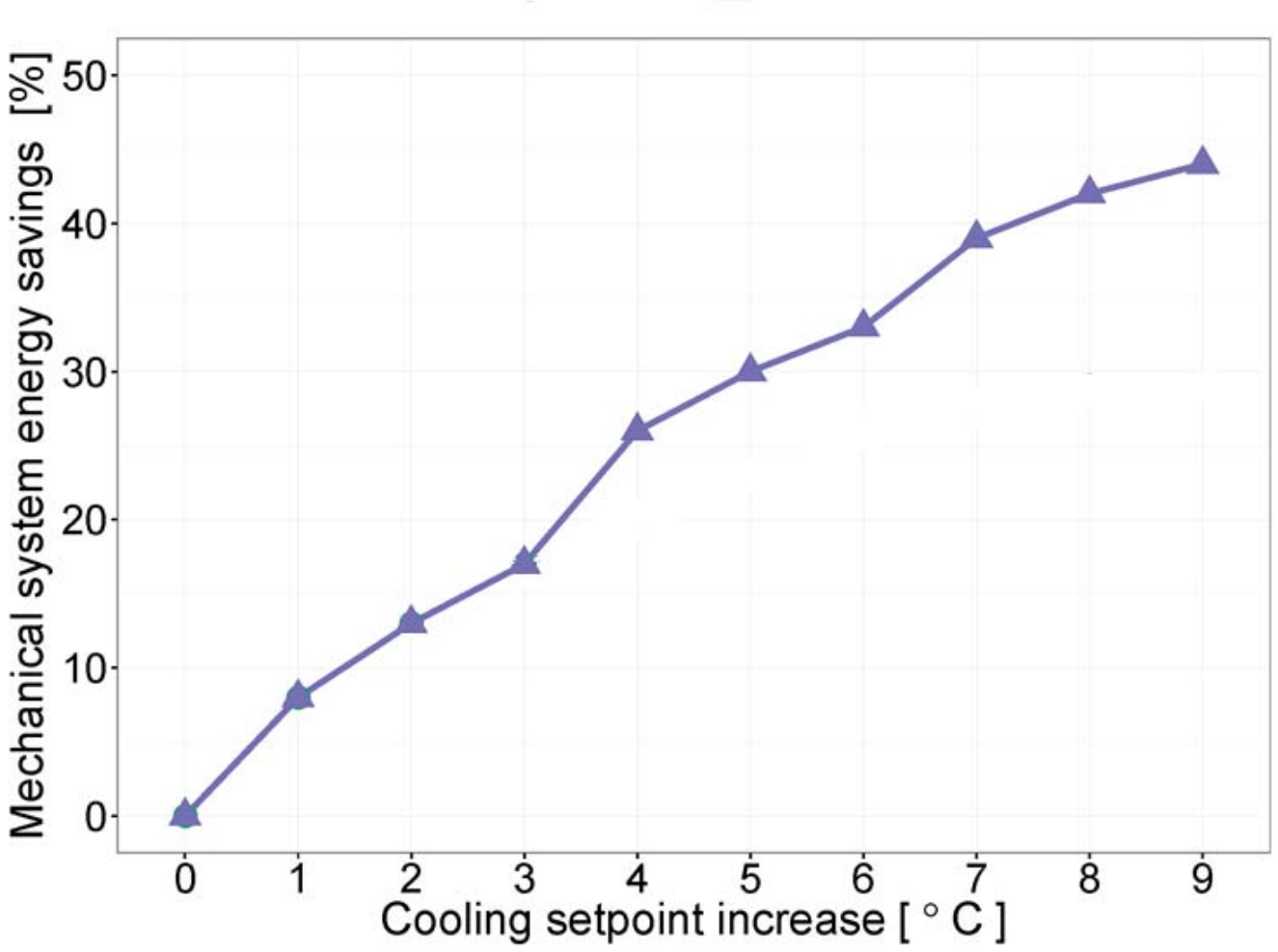
Cheung et al 2019 *Ongoing work*

Energy savings and inexpensive

100 – 1500 W
Thousands $

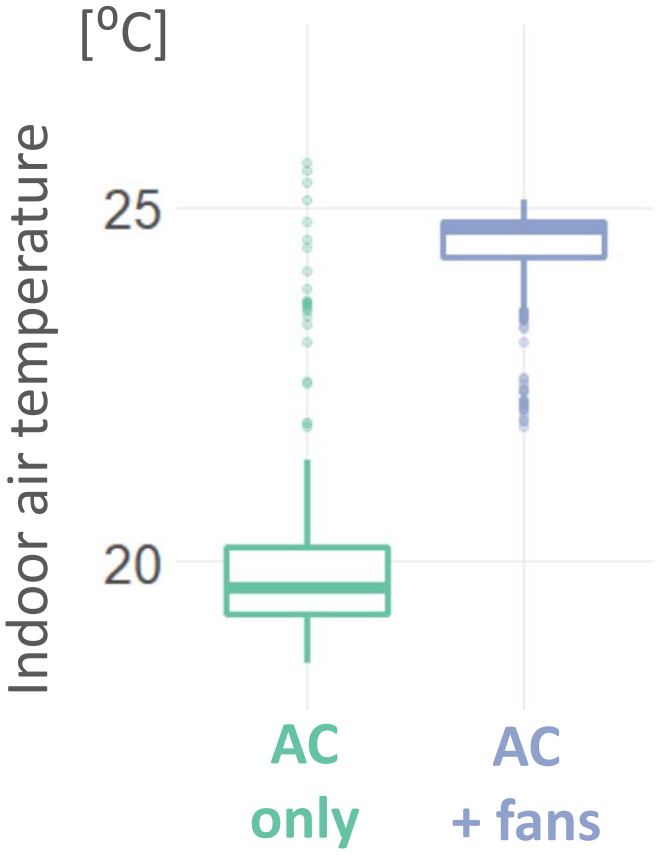
2-30 W
Hundreds $

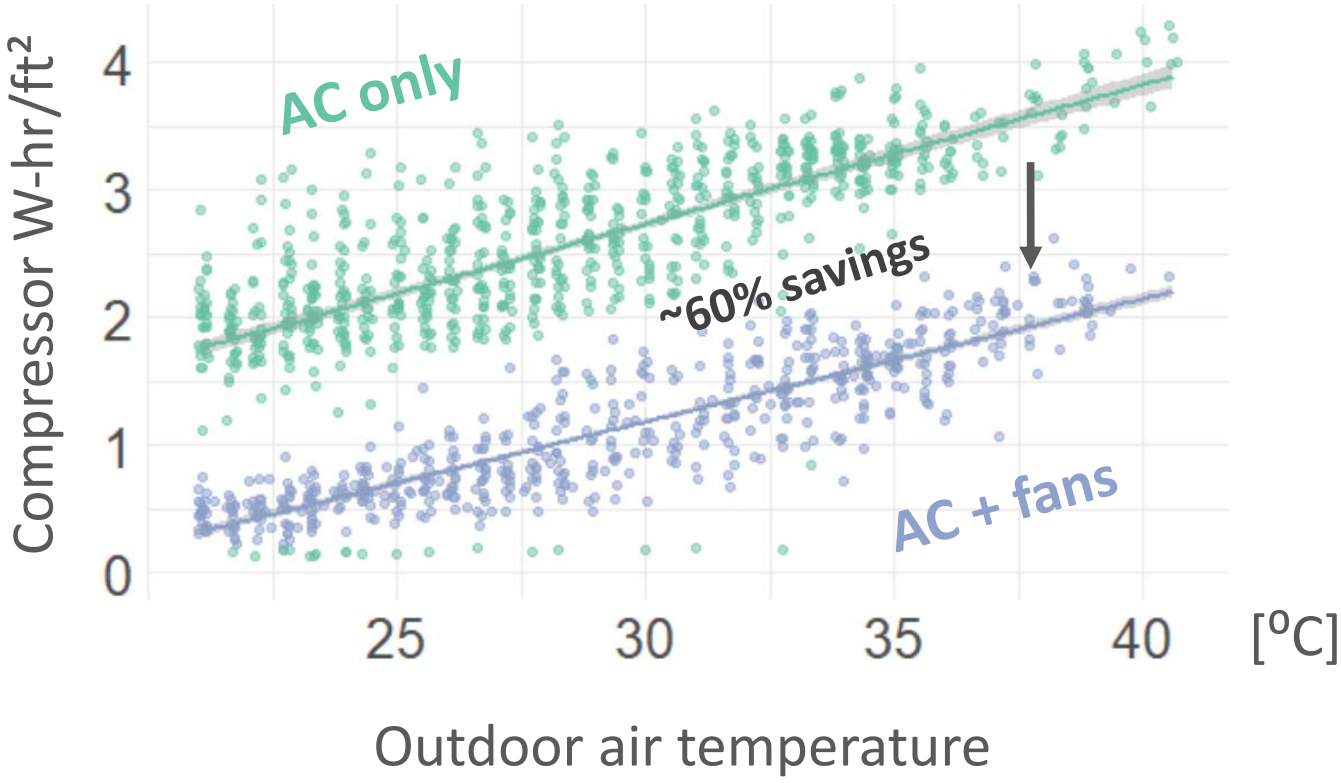
Saving energy: Simulations



Schiavon & Melikov 2008 *Energy and Buildings* - Hoyt et al. 2015 *Building and Environment.*
Duarte, Raftery, Schiavon 2017 *Energy Technology* and Rim, Schiavon, Nazaroff 2015 *PLOS ONE*

Energy savings: Measured in real building

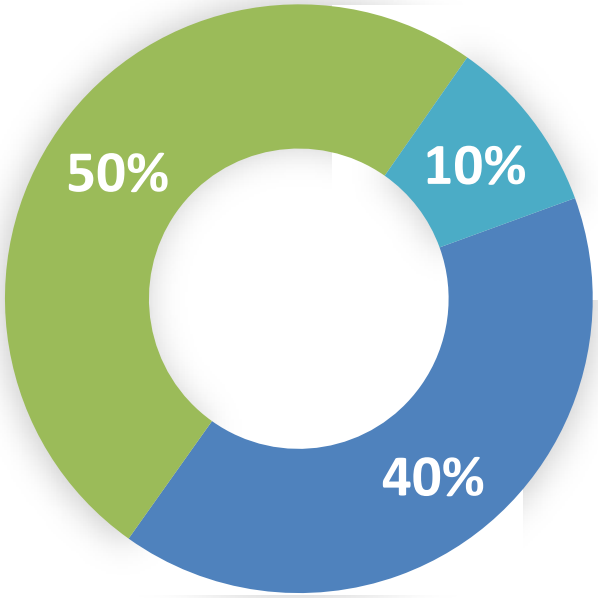




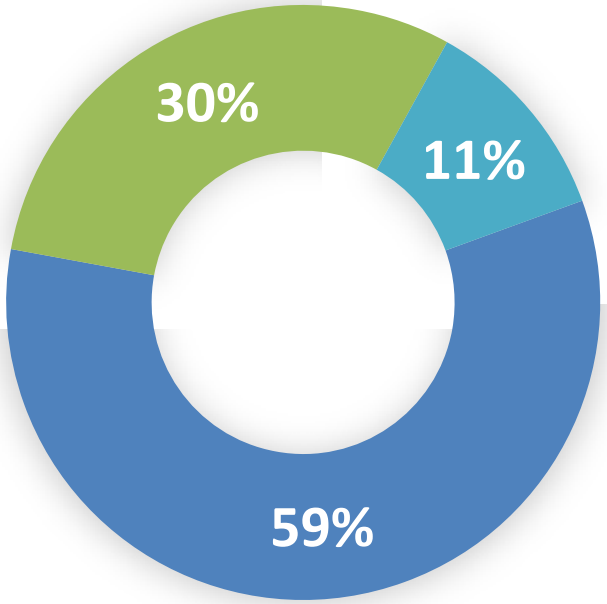
Miller, Raftery et al. 2019 Ongoing research

People want it: Air movement preference

Across all comfort conditions
N=35,000



For occupants who feel 'slightly warm'
N=6,400



Want more | No change | Want less

From ASHRAE Global Thermal Comfort Database II Source: CBE

Source: Aeratron

Conventional operation

Air temperature

22

Cooling setpoint

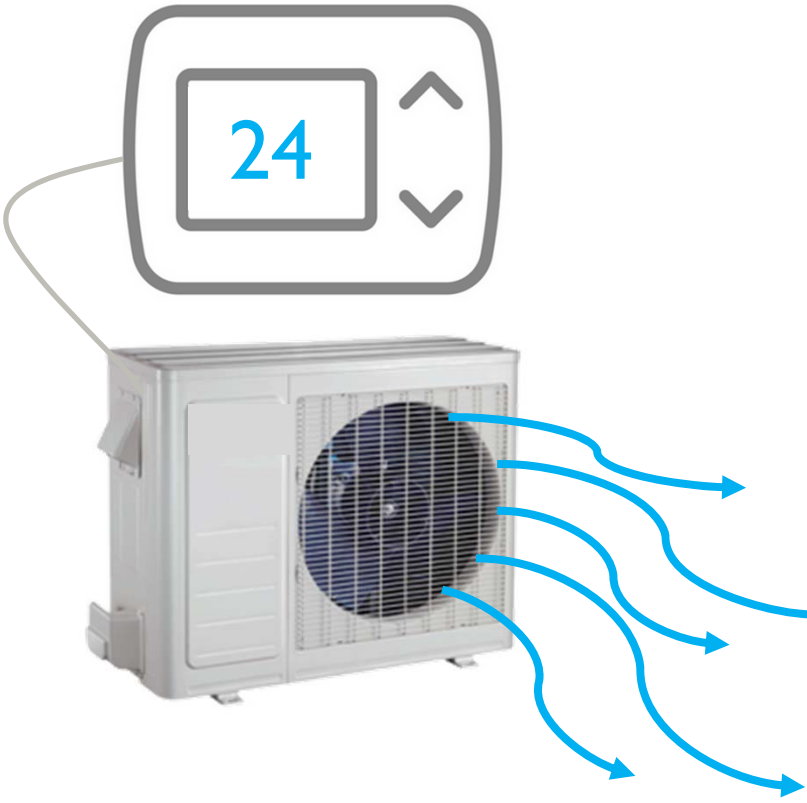
Source: Dana Miller

Conventional operation

Air temperature

24

Cooling setpoint



Source: Dana Miller

‘Fans first’ staged cooling with fans and AC

Air temperature

22

Cooling setpoint

24

Cooling setpoint

Source: Dana Miller

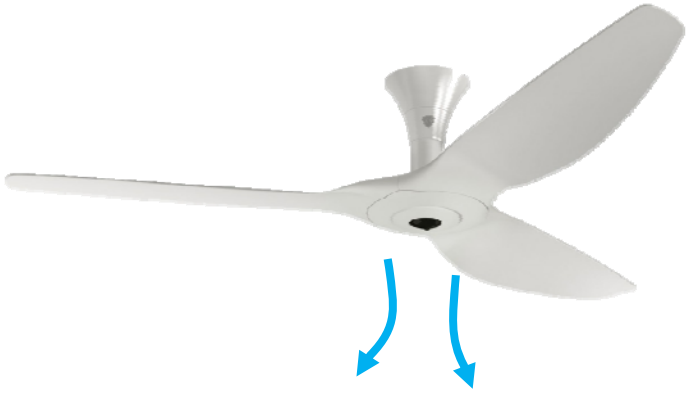
‘Fans first’ staged cooling with fans and AC

Air temperature

24

Cooling setpoint

24



Cooling setpoint

Source: Dana Miller

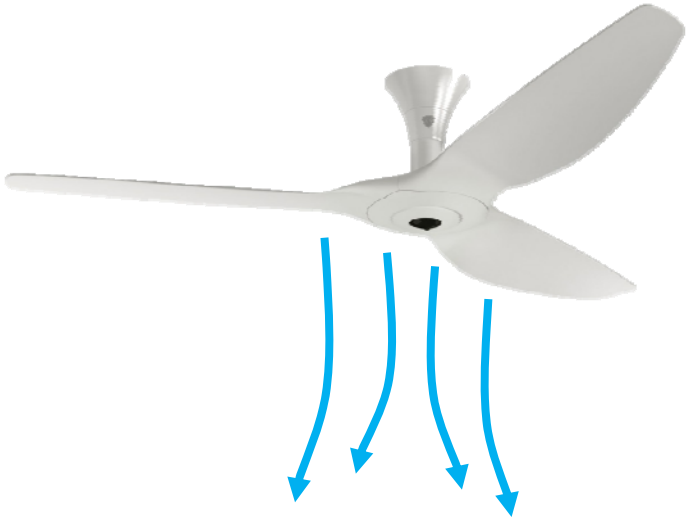
‘Fans first’ staged cooling with fans and AC

Air temperature

26

Cooling setpoint

24



Cooling setpoint

Source: Dana Miller

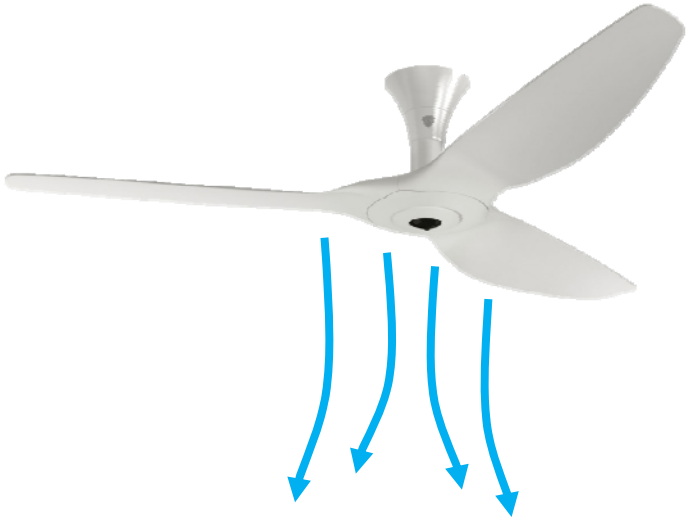
‘Fans first’ staged cooling with fans and AC

Air temperature

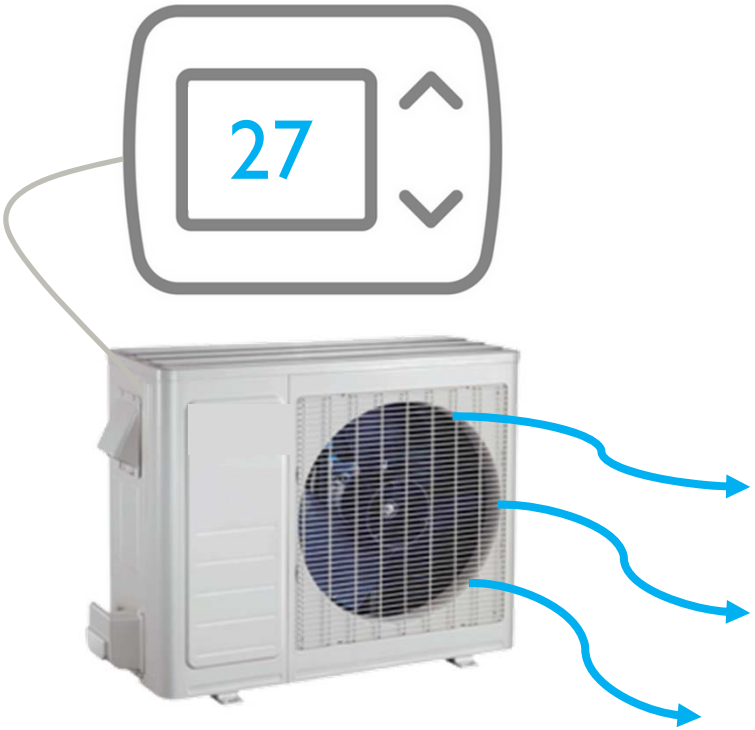
27

Cooling setpoint

24



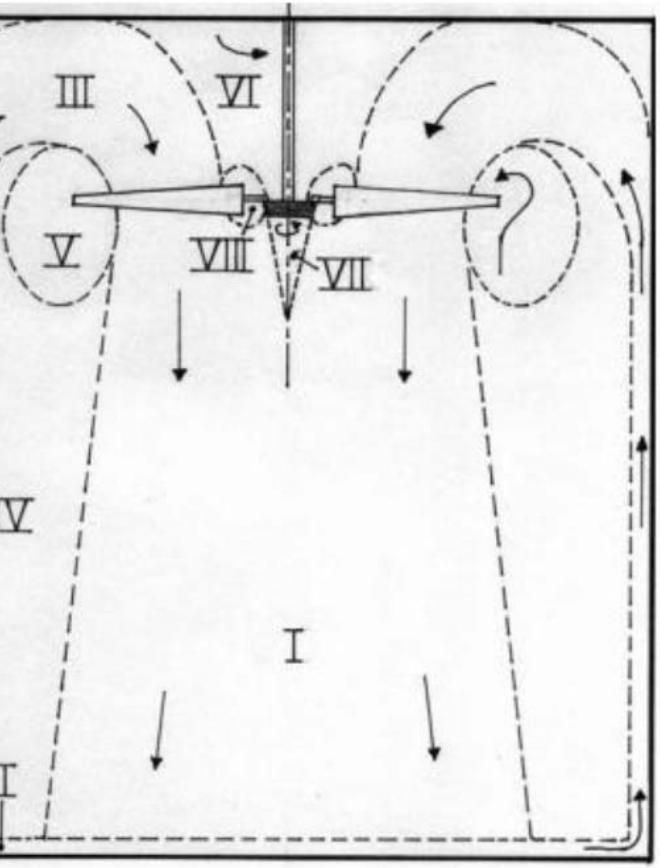
Cooling setpoint



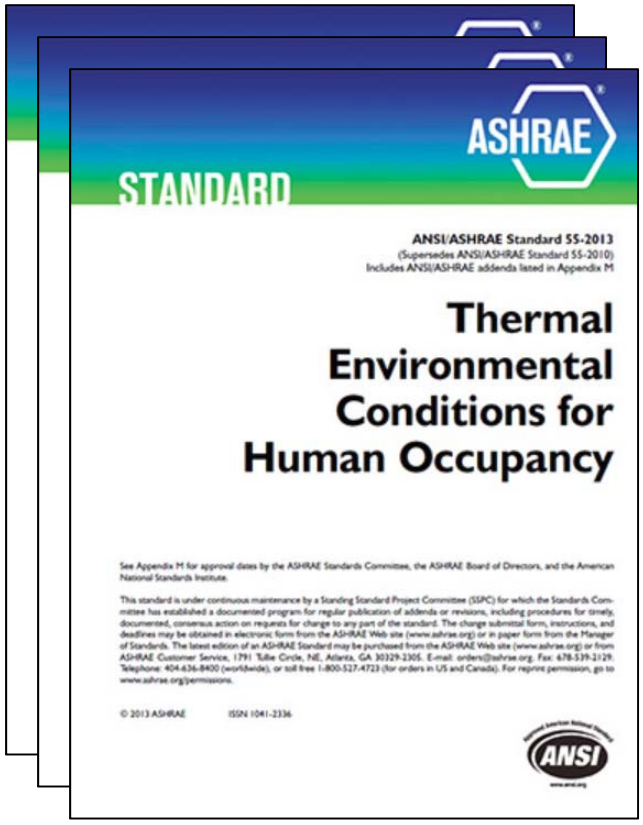
Source: Dana Miller

Why challenging?

Technical



Regulatory

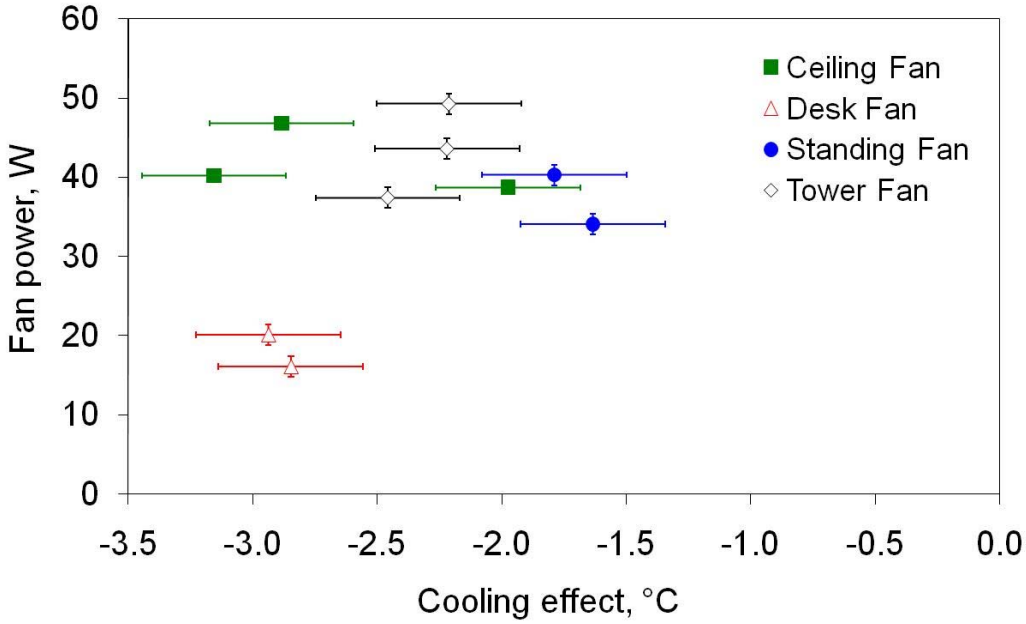


Cultural

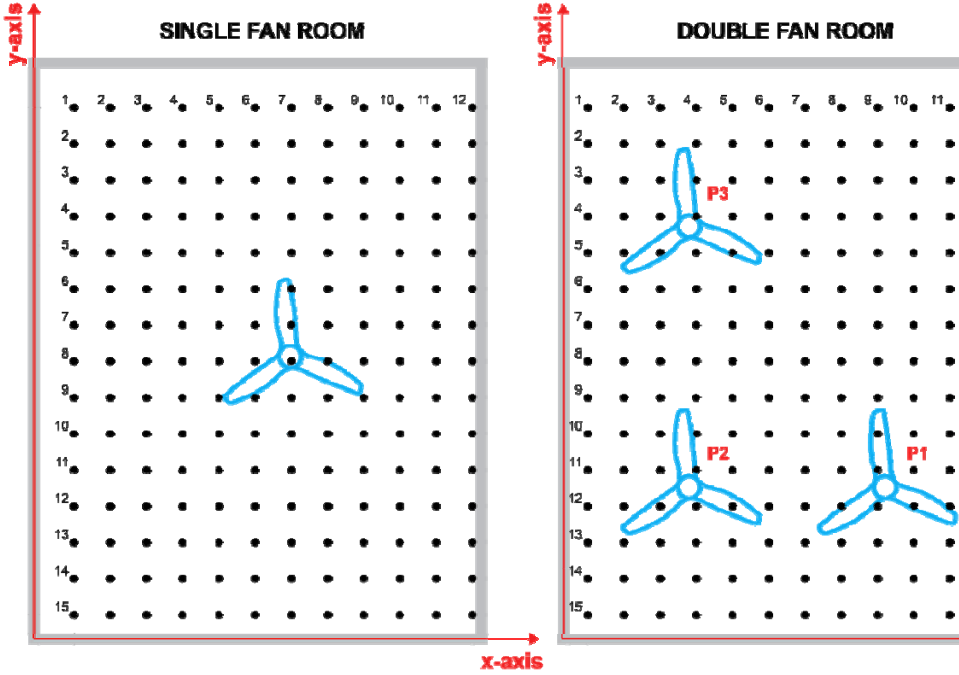
Cooling fan efficiency index (now included in ASHRAE 216)

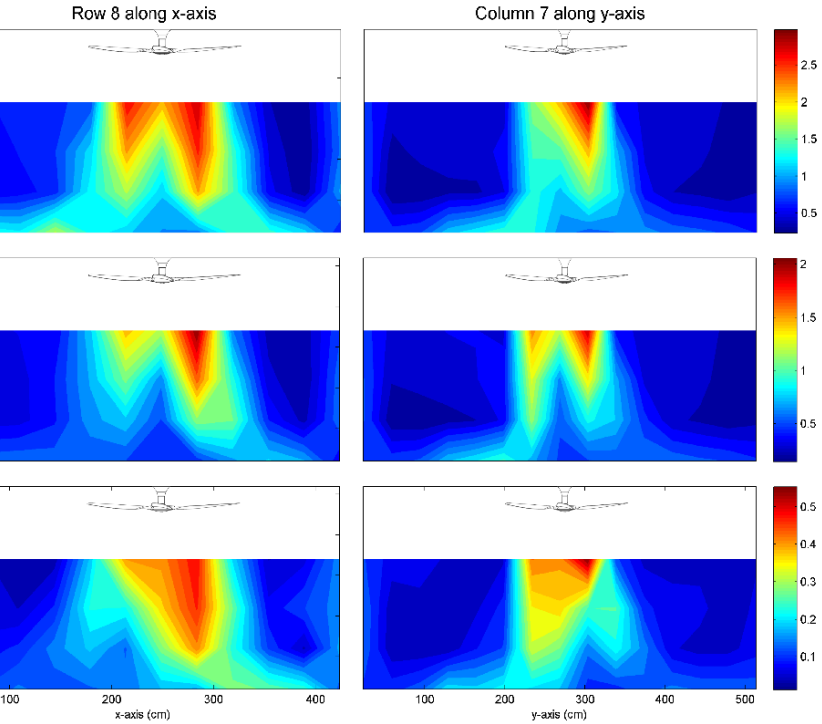
$$Efficiency = \frac{Output}{Input}$$

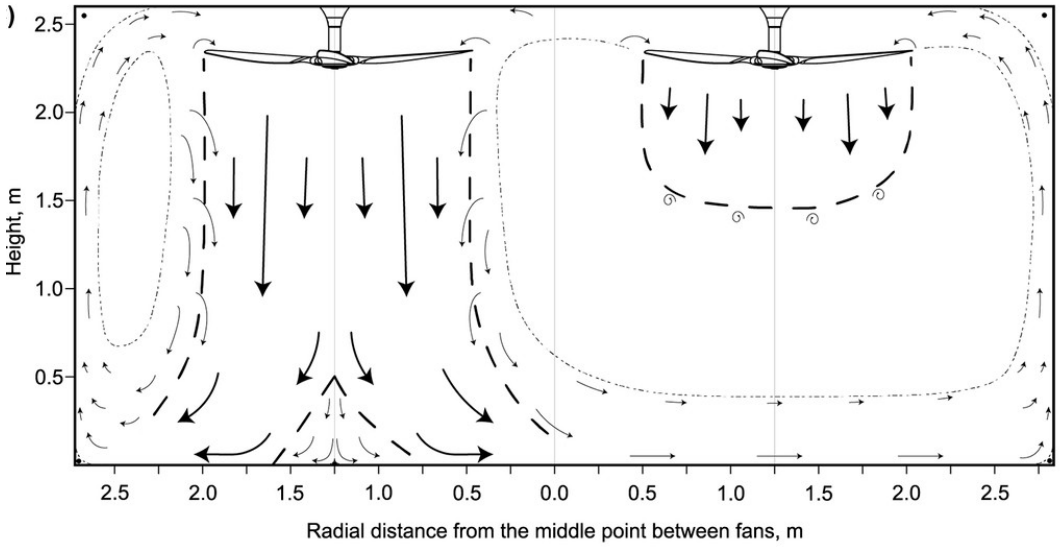
$$Cooling\ Fan\ Efficiency = \frac{Cooling\ effect\ [°C]}{Power\ [W]}$$



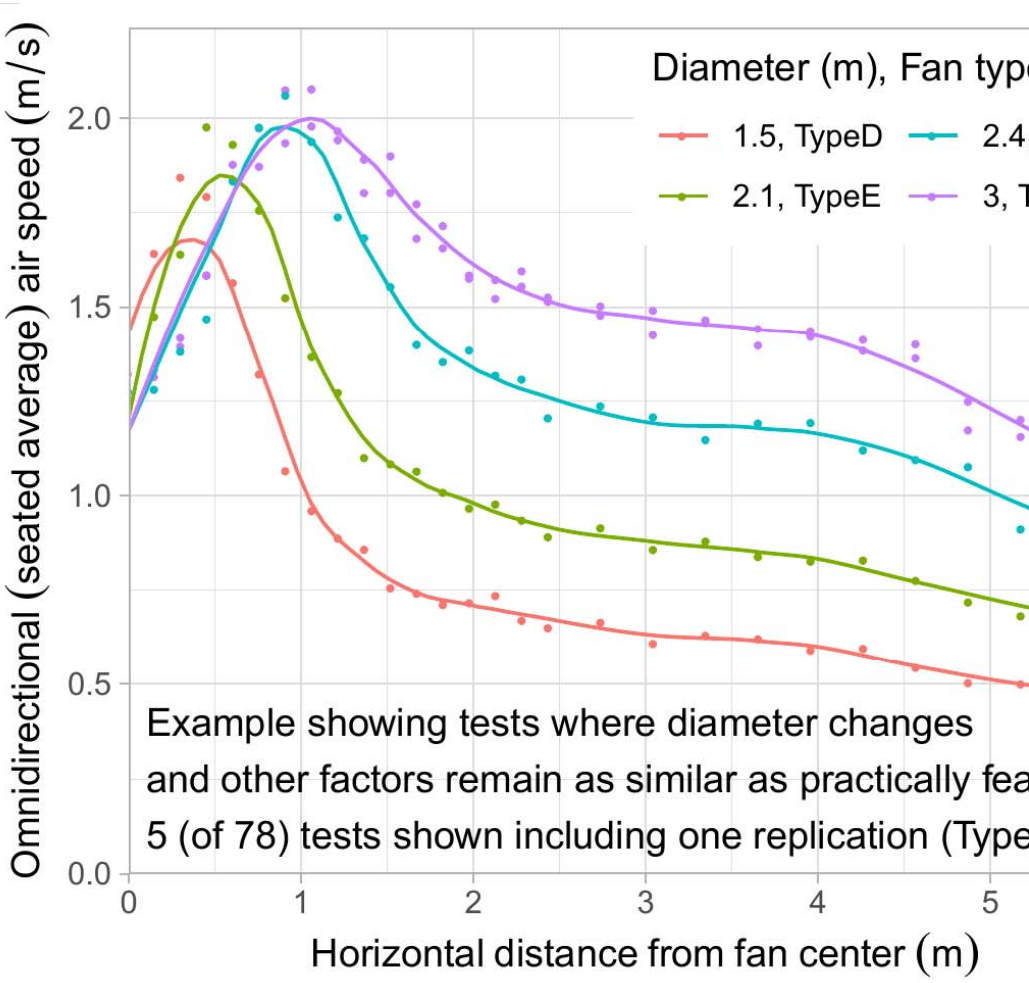
Schiavon & Melikov 2009 *HVAC&R Research* Photo source: Aeratron and Dyson





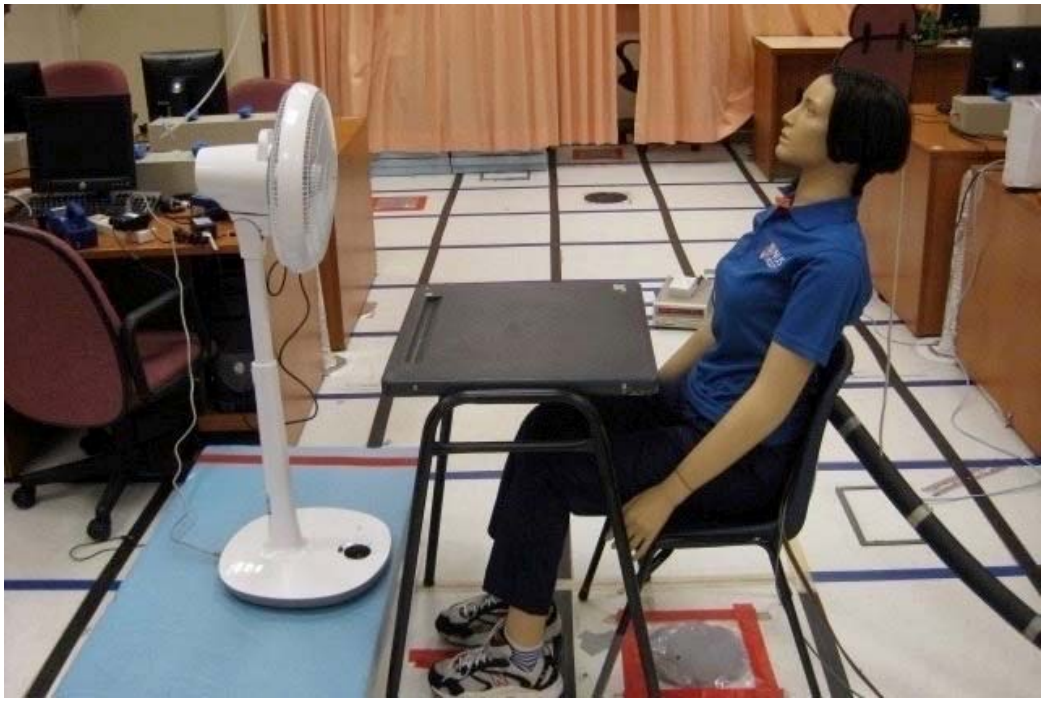


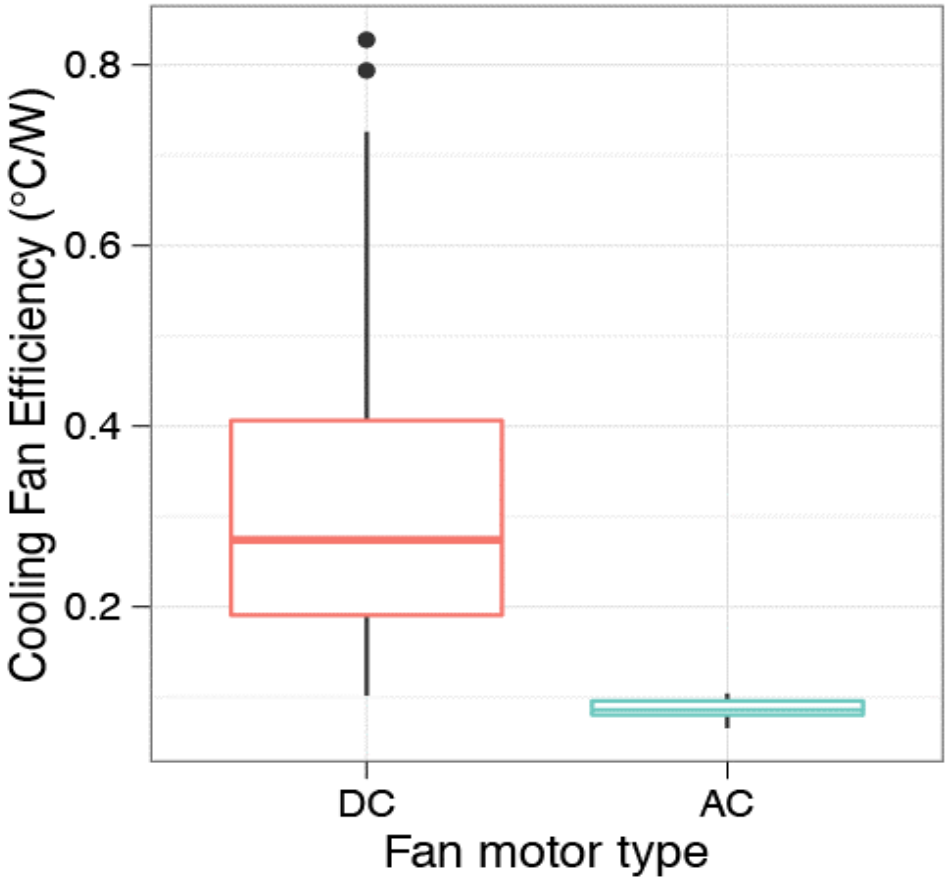
Shuo, Lipczynska, Schiavon, Arens 2018 *Building and Environment* https://cbe-berkeley.shinyapps.io/single-fan



Raftery et al. 2019 *Building and Environment*

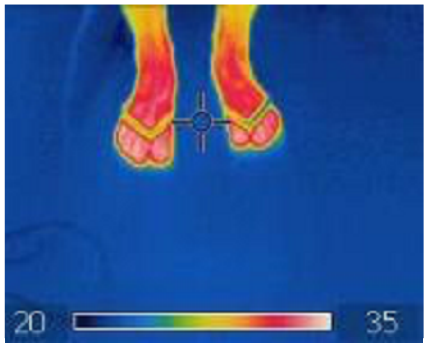
DC motors better than AC

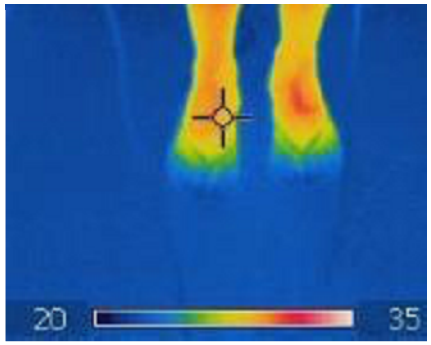


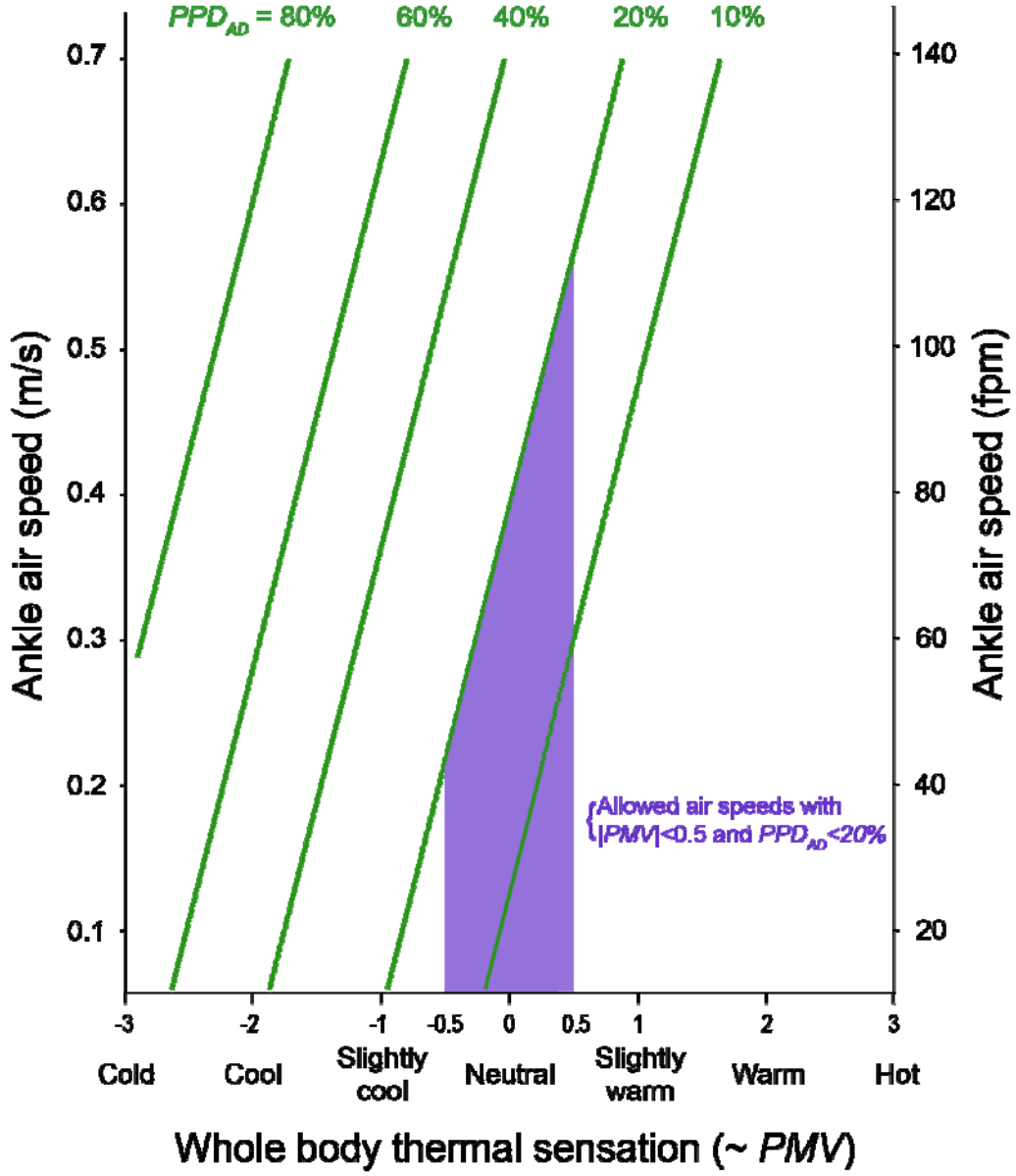


Yang, Schiavon, Sekhar, Cheong, Tham, Nazaroff 2014 *Building and Environment*

Ankle draft risk model (added to ASHRAE 55)

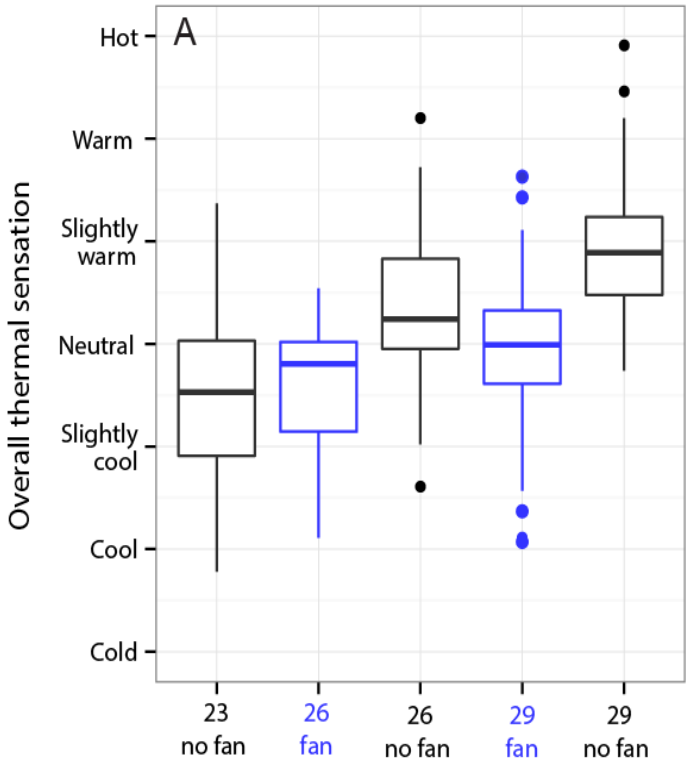


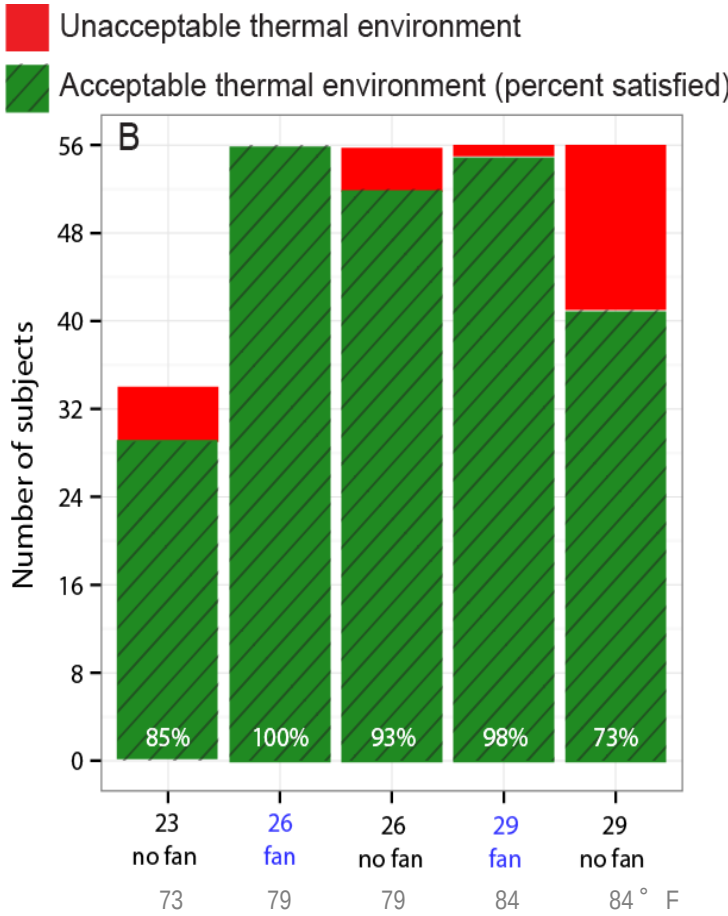




Liu, Schiavon, Kabanshi & Nazaroff 2017 *Indoor Air*

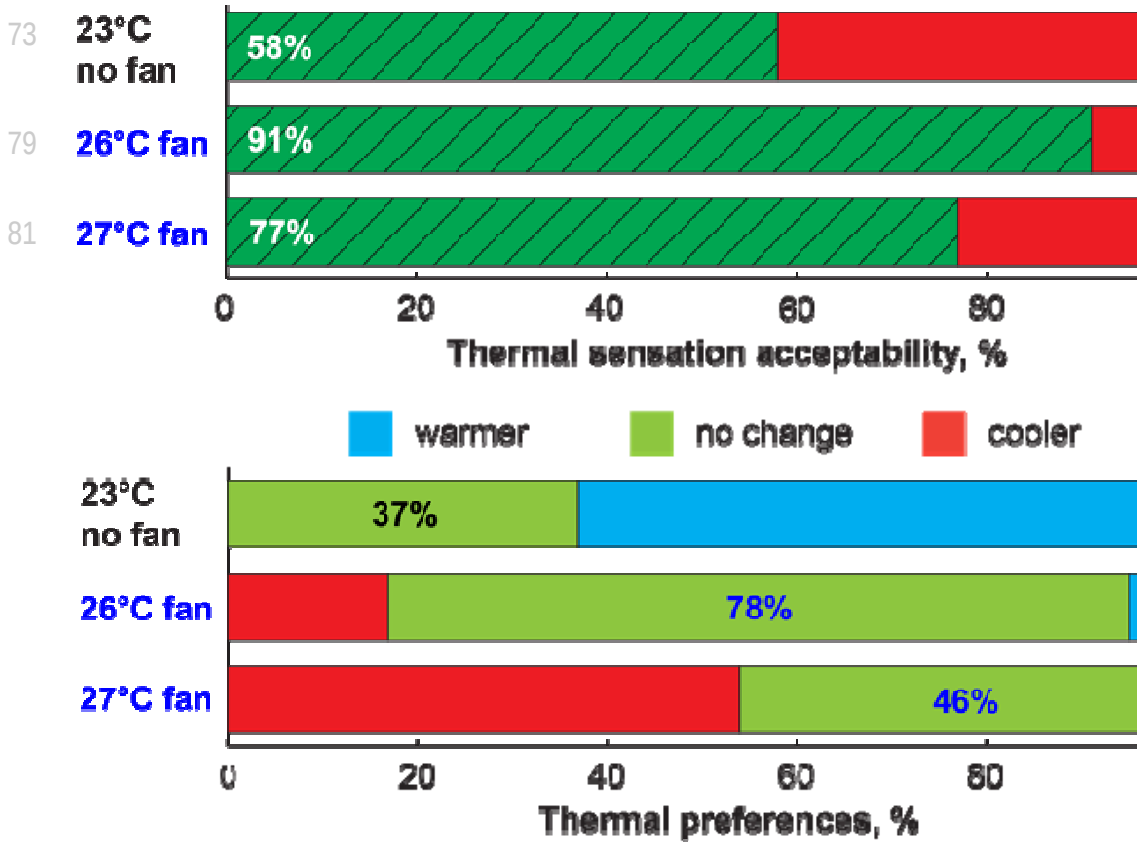
Personally controlled fan in Singapore





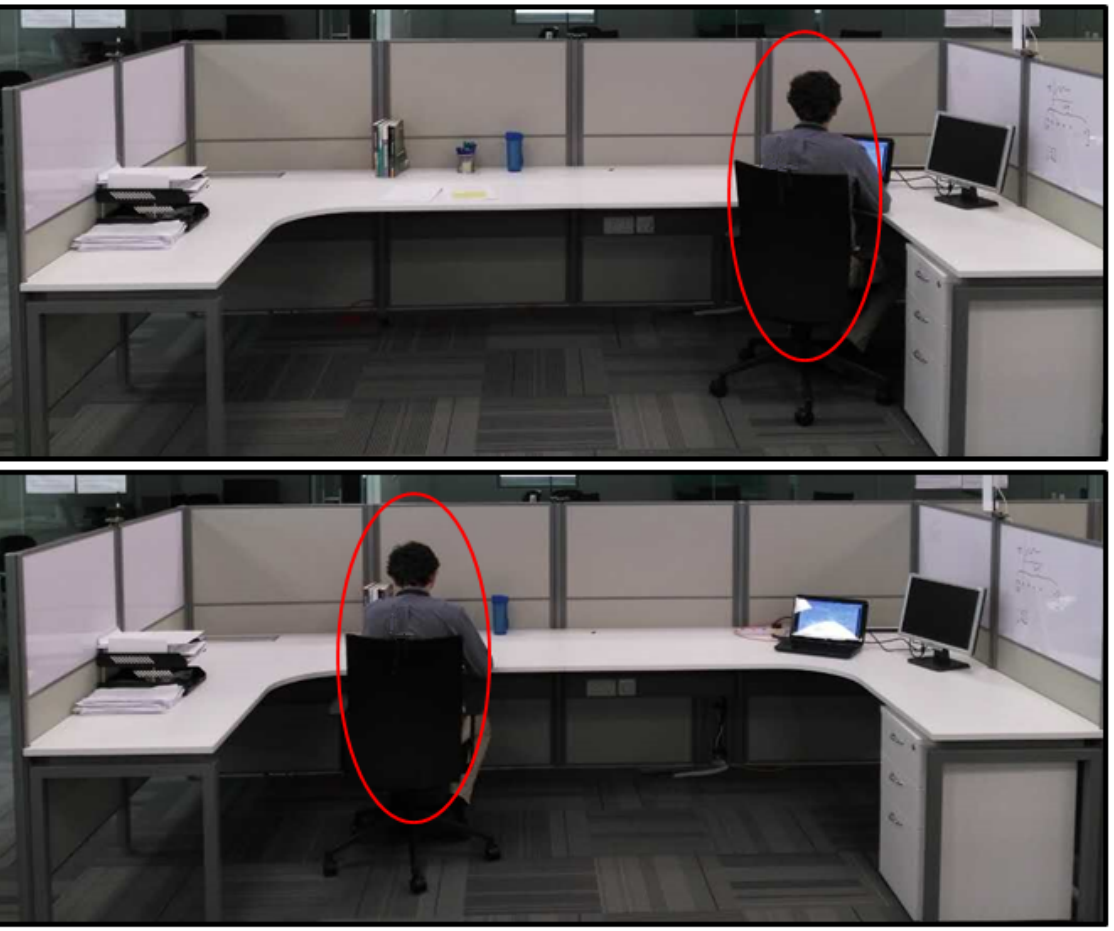
Schiavon et al 2017 *Indoor Air*

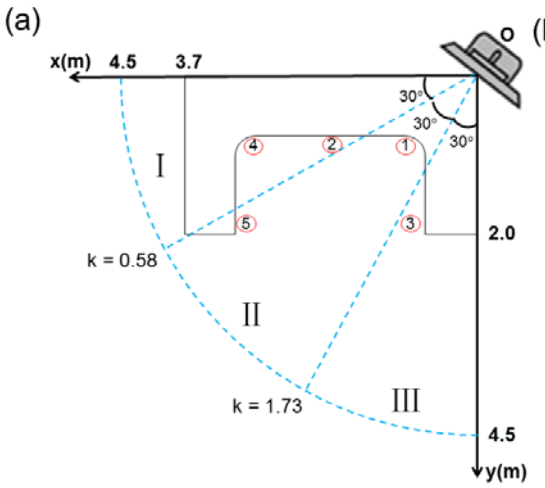
BOSCH field study

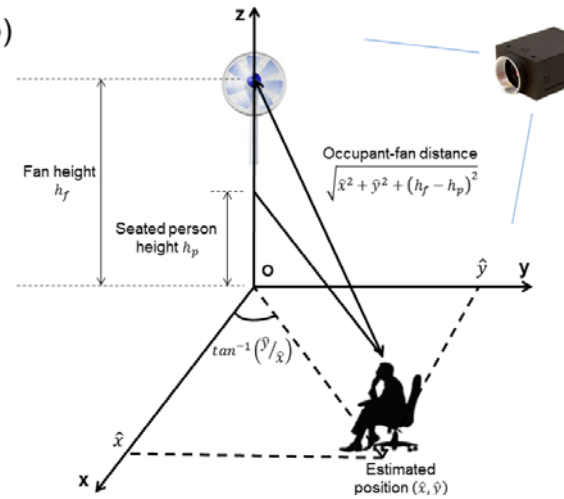


Lipczynska, Schiavon and Graham 2018 *Building and Environment*

Tracking fan using geofence and camera-based indoor localization

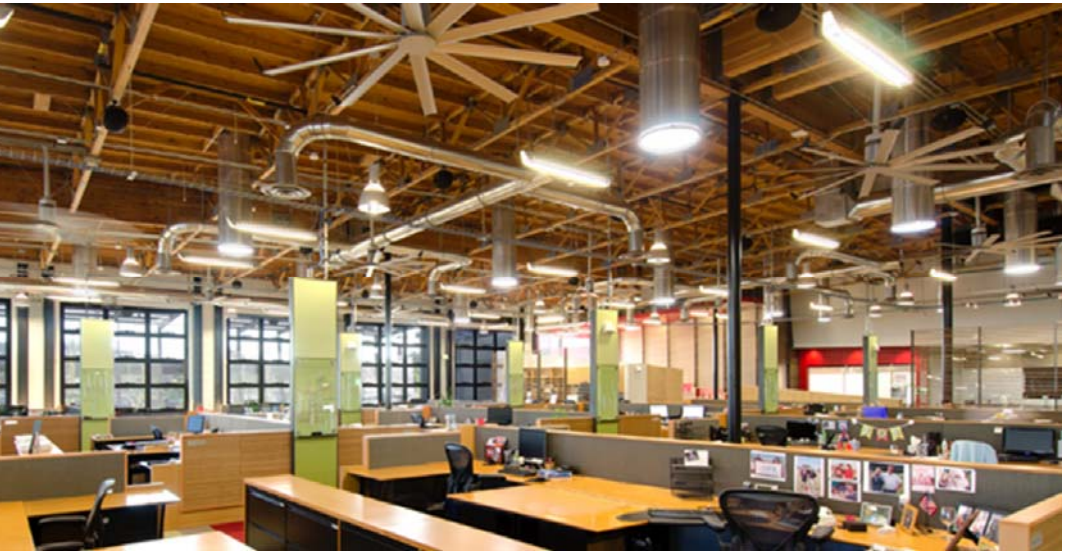


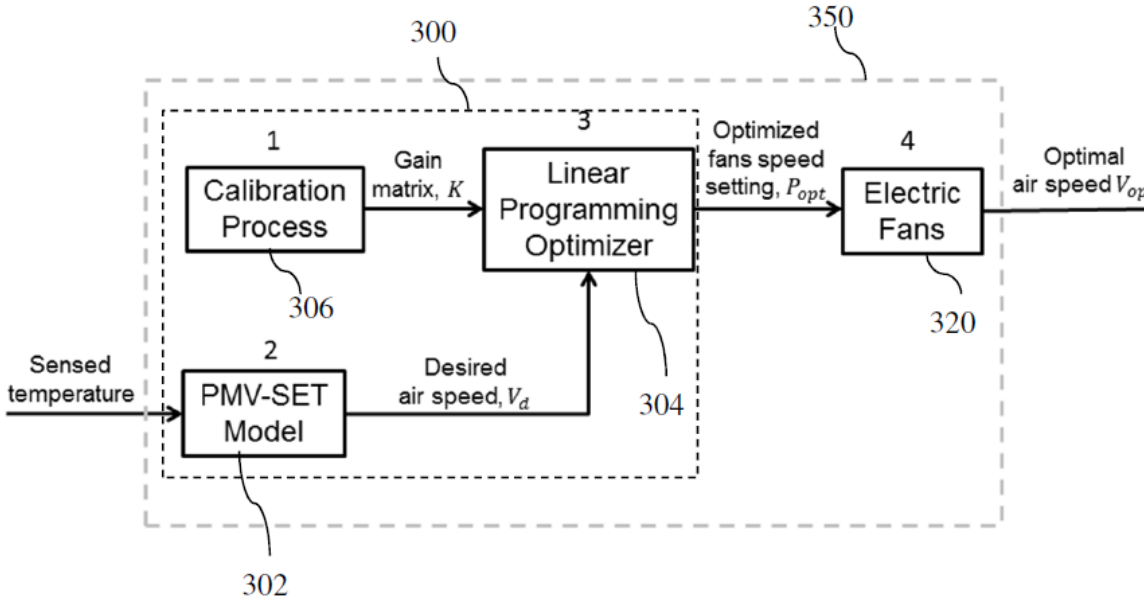


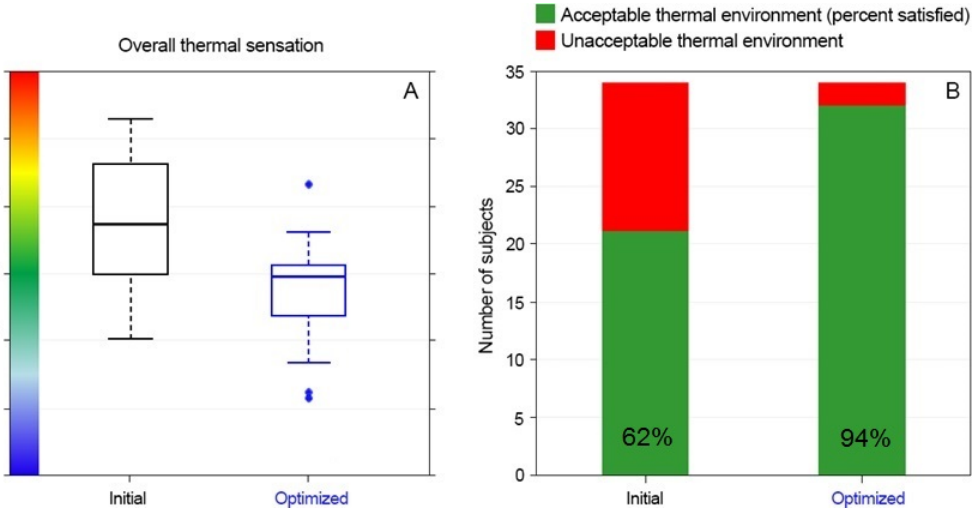


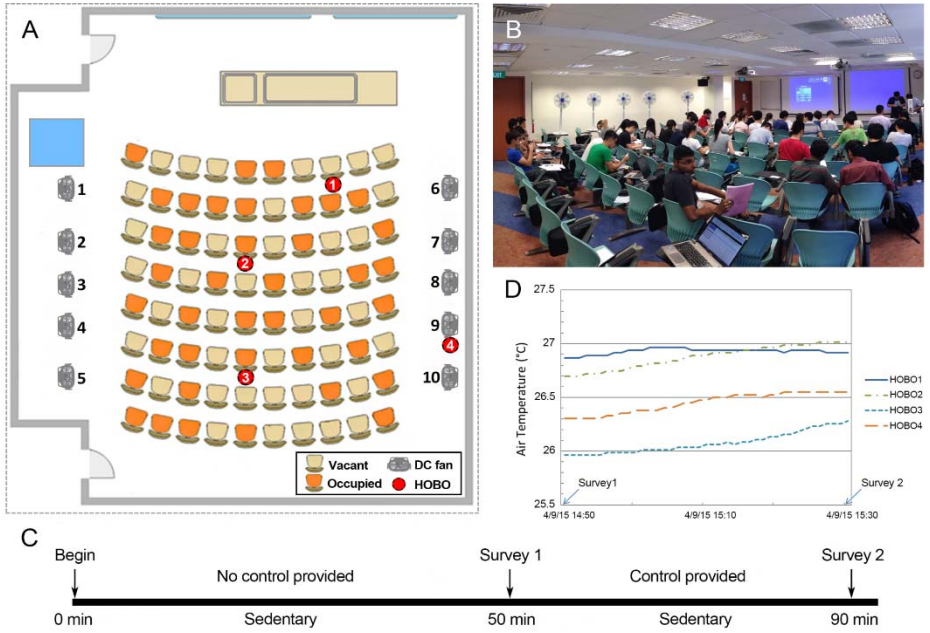
Liu, Yin, Ho, Ling, Schiavon 2017 *Building and Environment*

Source: Aeratron



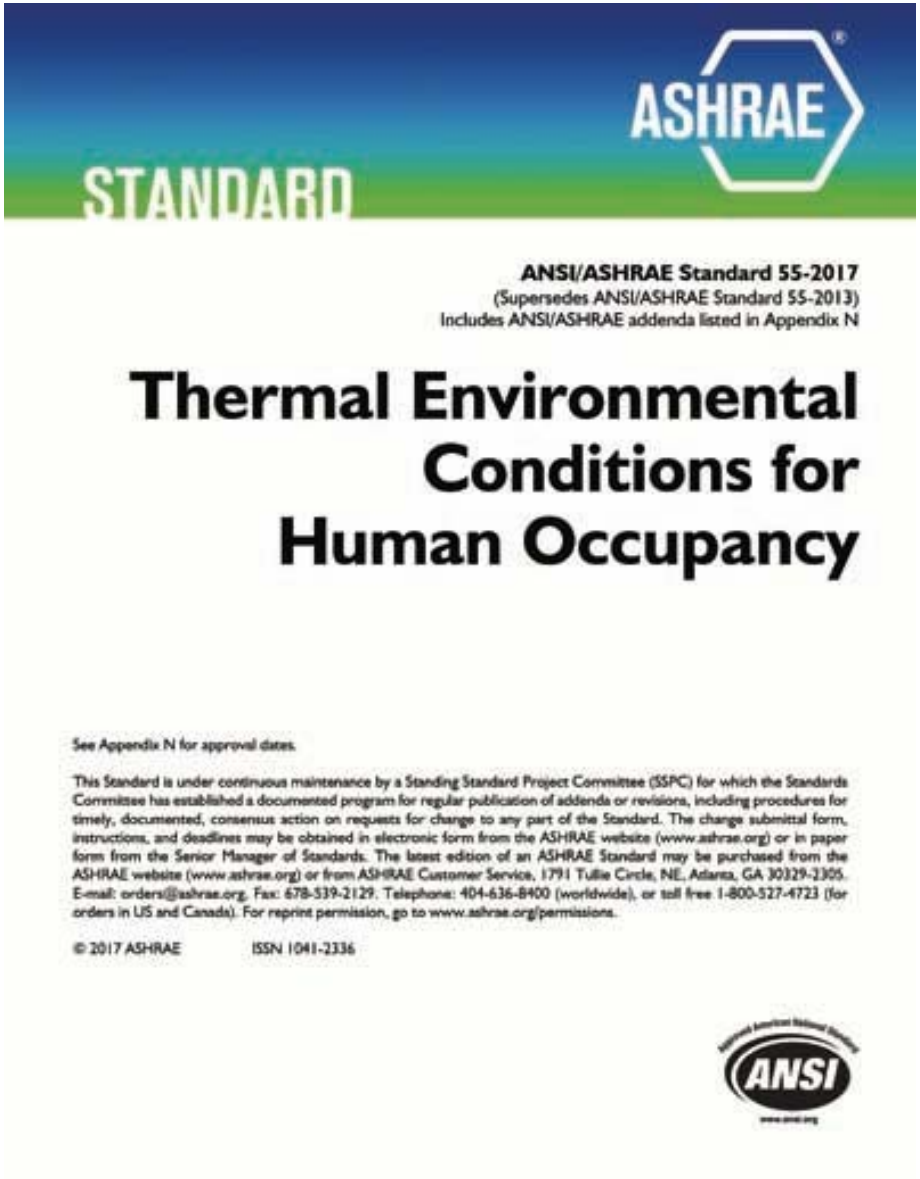






US provisional patent No. 62/307,223 Schiavon, Ho, Ling, Liu, Yin. Figure top right: DPR HQ, Phoenix AZ

Update standards: ASHRAE Standard 55



STANDARD

ASHRAE

ANSI/ASHRAE Standard 55-2017
(Supersedes ANSI/ASHRAE Standard 55-2013)
Includes ANSI/ASHRAE addenda listed in Appendix N

Thermal Environmental Conditions for Human Occupancy

See Appendix N for approval dates.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE website (www.ashrae.org) or in paper form from the Senior Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

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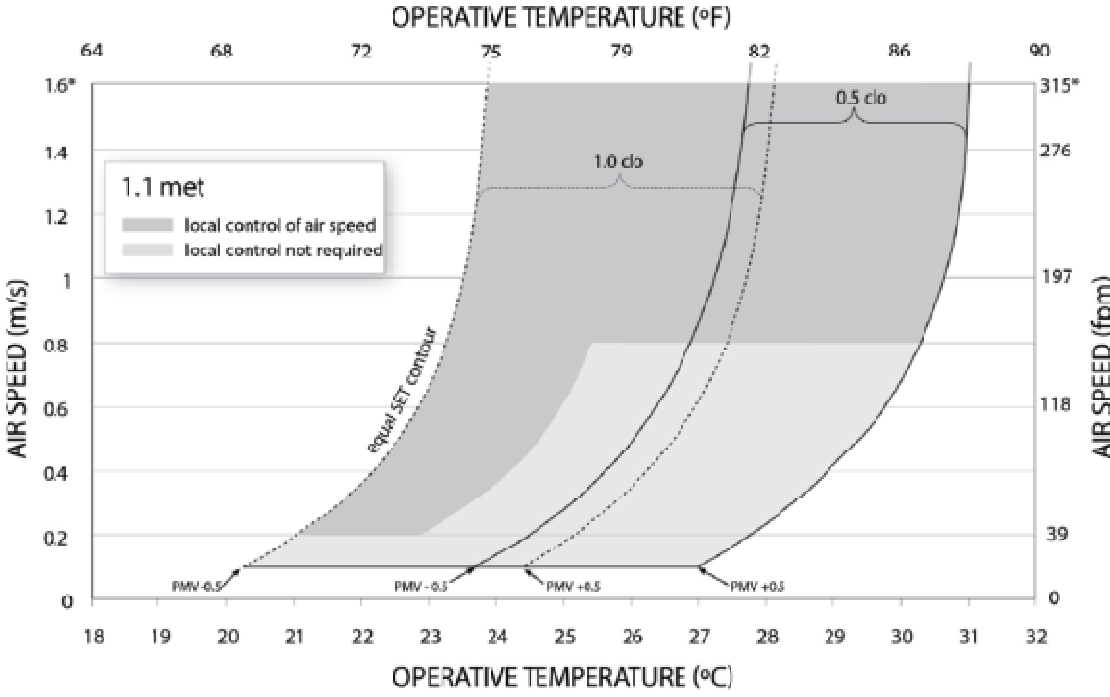
ANSI



*There is no upper limit to air speed when occupants have local control.

CBE Thermal Comfort Tool

ASHRAE-55 | EN-15251 | Compare | Ranges | Upload

Select method: PMV method

Air temperature
25 °C — Use operative temperature

Mean radiant temperature
25 °C

Air speed
0.1 m/s — Local air speed control

Humidity
50 % — Relative humidity

Metabolic rate
1.1 met — Typing: 1.1

Clothing level
0.5 clo — Typical summer indoor

Create custom ensemble

Dynamic predictive clothing

LEED documentation

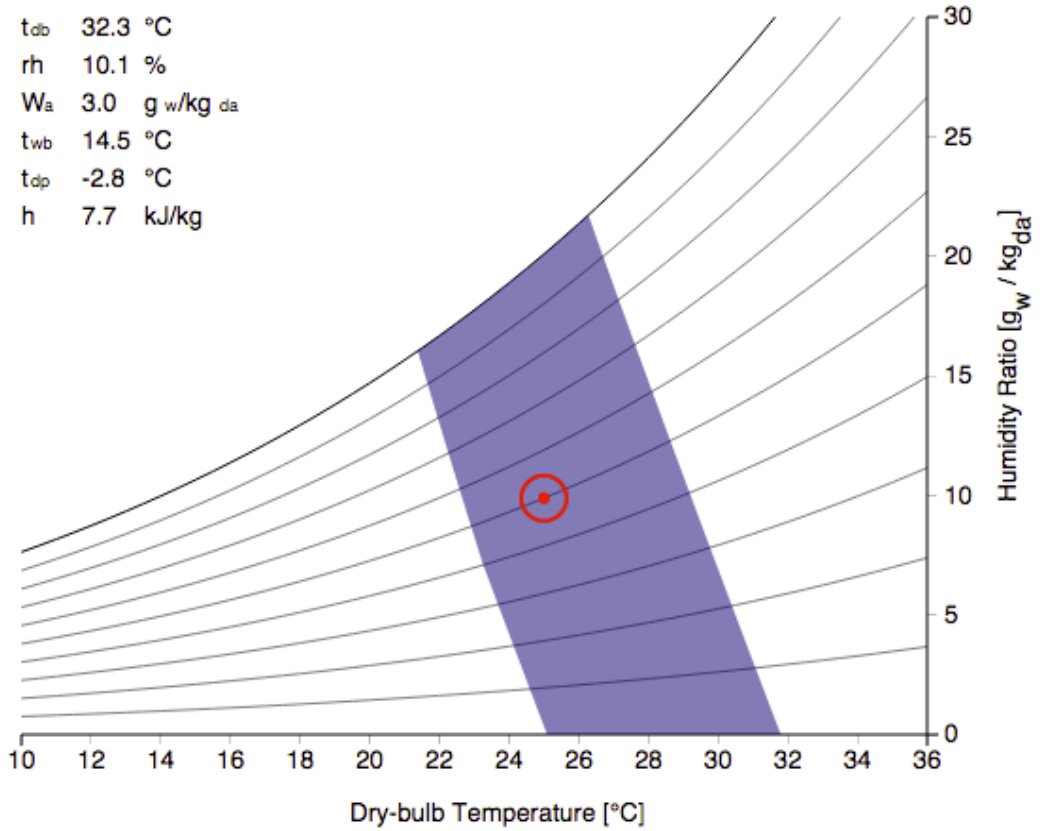
Globe temp | SolarCal | Specify pressure | SI IP | Local discomfort | ? Help

✔ Complies with ASHRAE Standard 55-2013

PMV	-0.13
PPD	5%
Sensation	Neutral
SET	24.5°C

Psychrometric chart (air temperature)

t_{db}	32.3	°C
rh	10.1	%
W_a	3.0	g w/kg da
t_{wb}	14.5	°C
t_{dp}	-2.8	°C
h	7.7	kJ/kg



Hoyt & Schiavon et al CBE Thermal Comfort Tool for ASHRAE-55 comfort.cbe.berkeley.edu

New standards: ASHRAE Standard 216

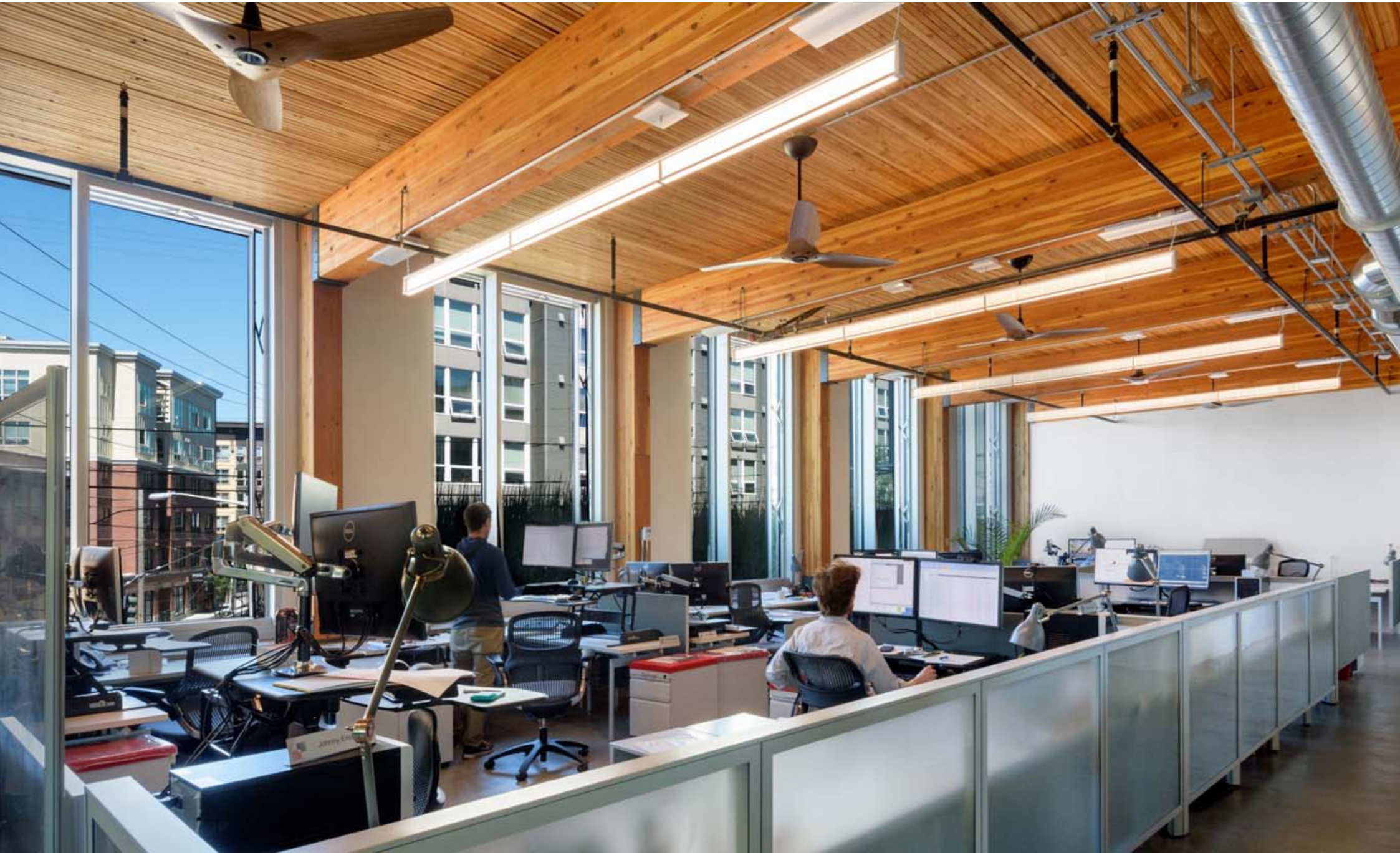
ANSI/ASHRAE Standard 216P
Methods of Test for Determining Application Data of Overhead Circulator Fans

SPC 216

Working Draft 01

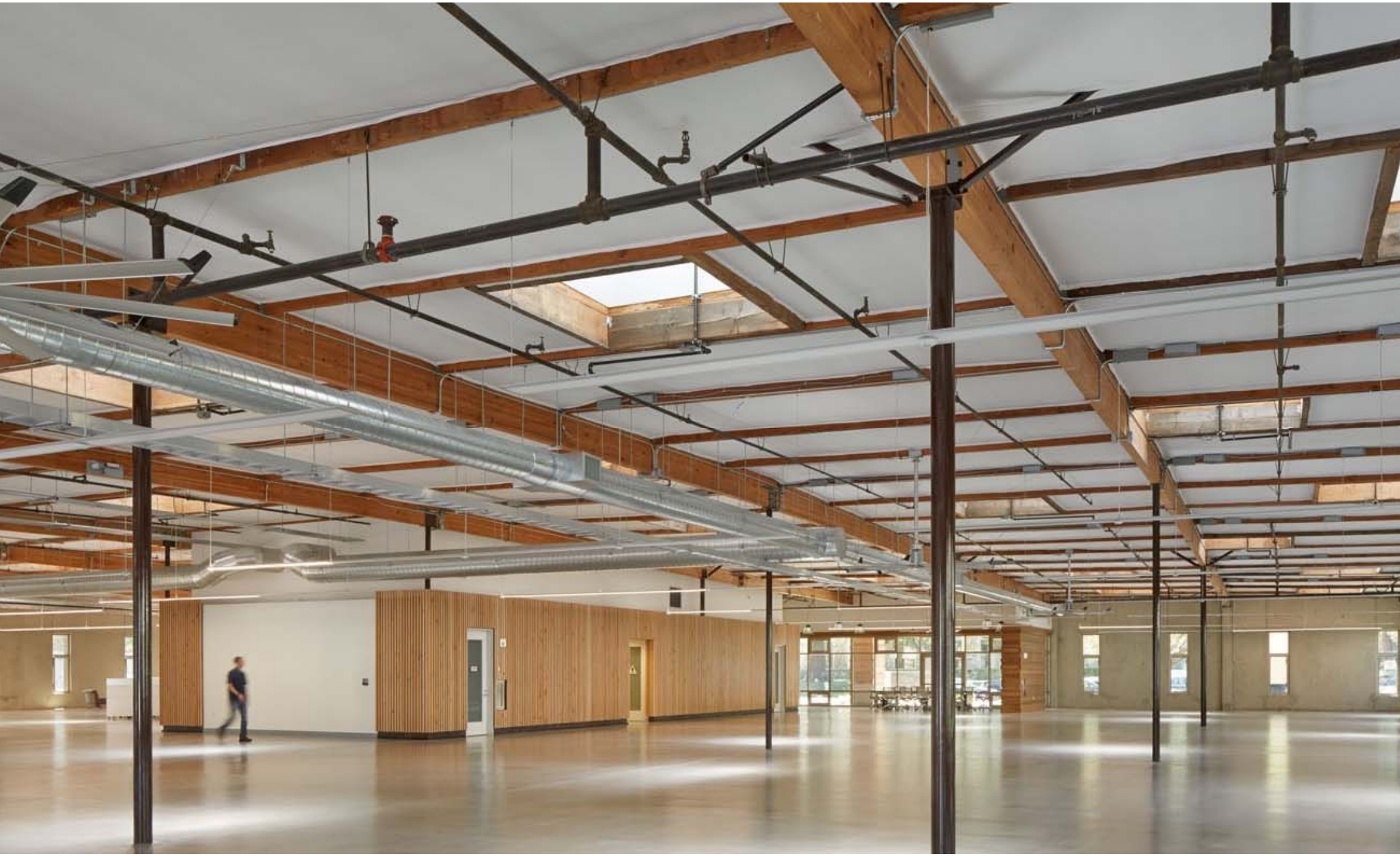
TABLE OF CONTENTS

Commonwealth Club, San Francisco, CA



Bullitt Center, Seattle, WA

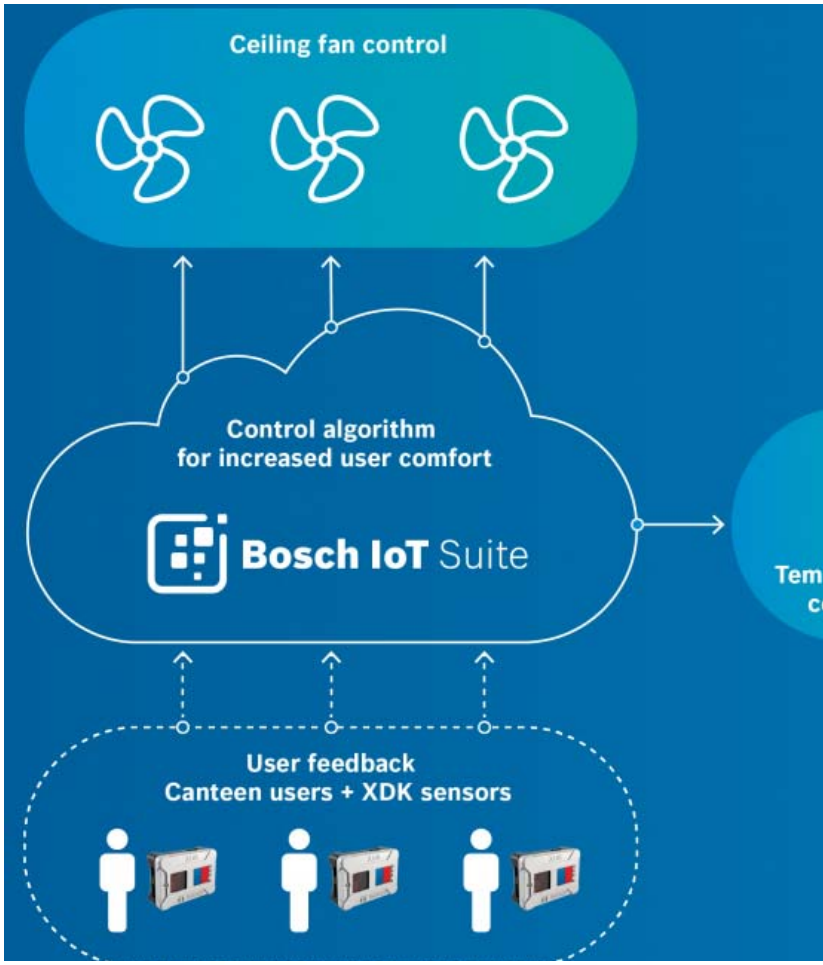
Rocky Mountain Institute, Basalt, CO



435 Indio Way, Bay Area, CA

Davis, CA

Bosch, Singapore

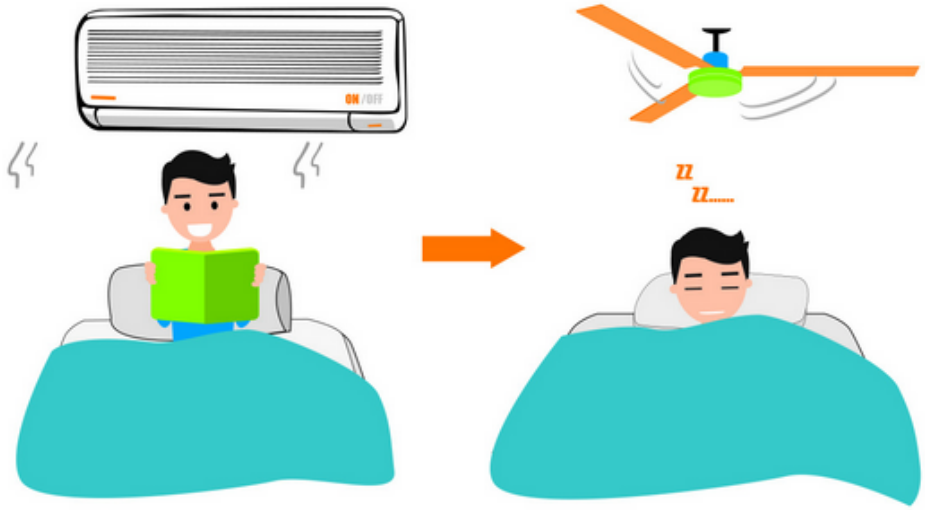


og.bosch-si.com/building/connected-canteen-iot-project-singapore/

NUS SDE4 - Kessling et al. 2016 *PLEA.* Photo R Gardiner

Save money and increase comfort at home in Singapore

It's not cool to let the air-con run for a long time.
Switch to a fan after a short while and **save** about **$340** a year.



Beat the heat with a fan instead of an air-con.
Save around **$400** a year!

https://www.e2singapore.gov.sg/households/saving-energy-at-home

Muji Circulator Fan

MUJI desk fan

Miniso fans

Dyson fans

Future research needs

- Should we use ceiling or desk fans?
- How to coordinate and control fans?
- How can we mitigate the lack of homogeneity generated by ceiling fans?
- Can we have air movement without visible rotating blades?
- How much can we reduce ductwork and number of diffusers?

We do not have

- Simplified model to predict air distribution without the need of CFD
- Lab to test and certify fans performance
- Design guidelines

Photo: G. Paliaga

A Academy ZEB+ building renovation

Thank you

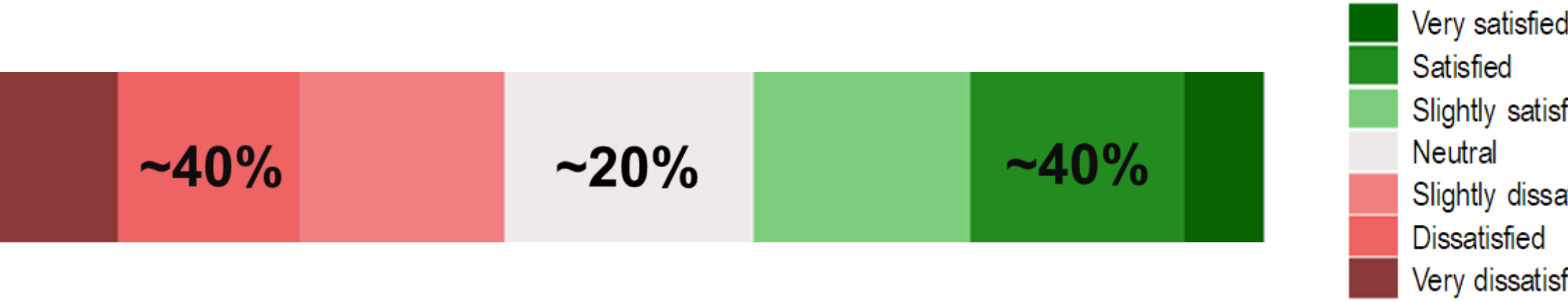
schiavon@berkeley.edu

David and Lucile Packard Foundation HQ

SinBerBEST

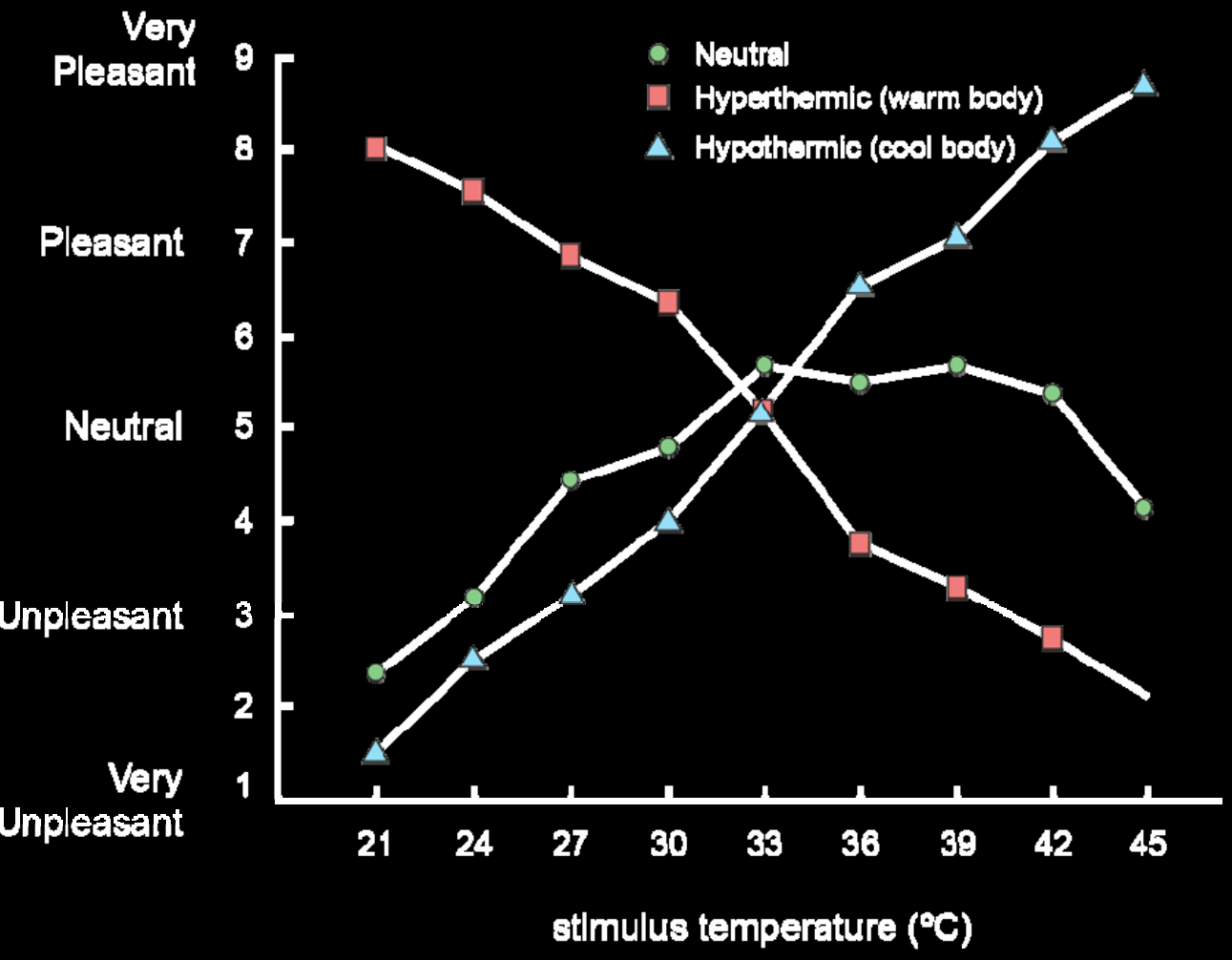
Building Efficiency and Sustainability in the Tropics

How satisfied are you with the temperature of your workspace?



Karmann, Schiavon, Arens 2018 *Windsor Conference*

Thermal pleasure



Source: Thomas Parkinson - Modified after Mower, 1976

George Washington's Fan Chair, Mt Vernon, VA, circa 1790,

CBE Indoor Environmental Quality survey

w satisfied are you with your ability to adjust your furniture to et your needs?

y Satisfied  Very Dissatisfied

Overall building

Overall workplace

Acoustic quality

Air quality

Cleanliness & maintenance

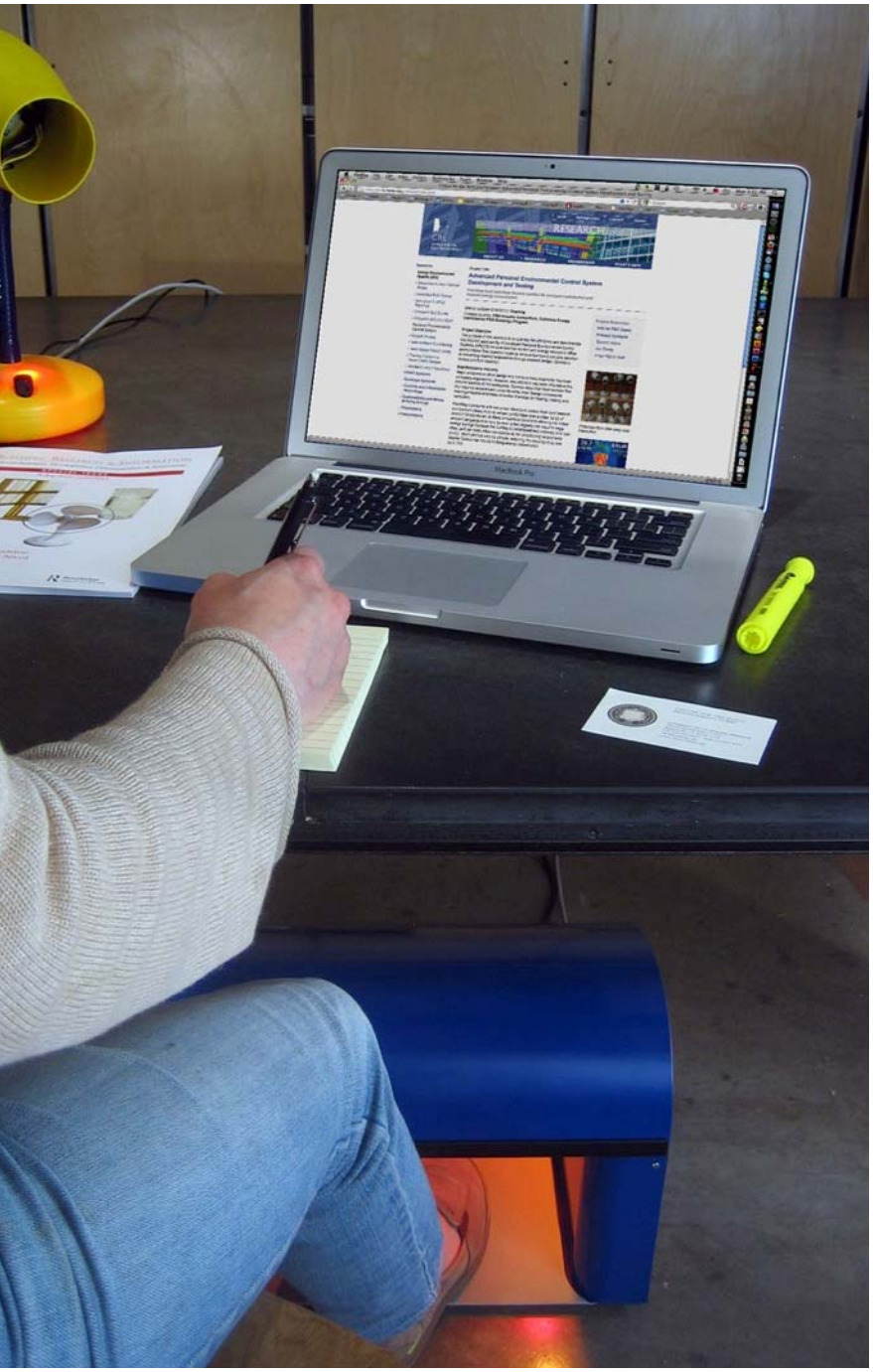
ighting

)ffice furnishings

)ffice layout

'hermal Comfort

cbe.berkeley.edu/survey Leader: Lindsay Graham



CBE personal comfort systems - desk fan, foot warmer, heated and cooled chair


Illustration by David Lehrer; © 2015 Regents of the University of Ca